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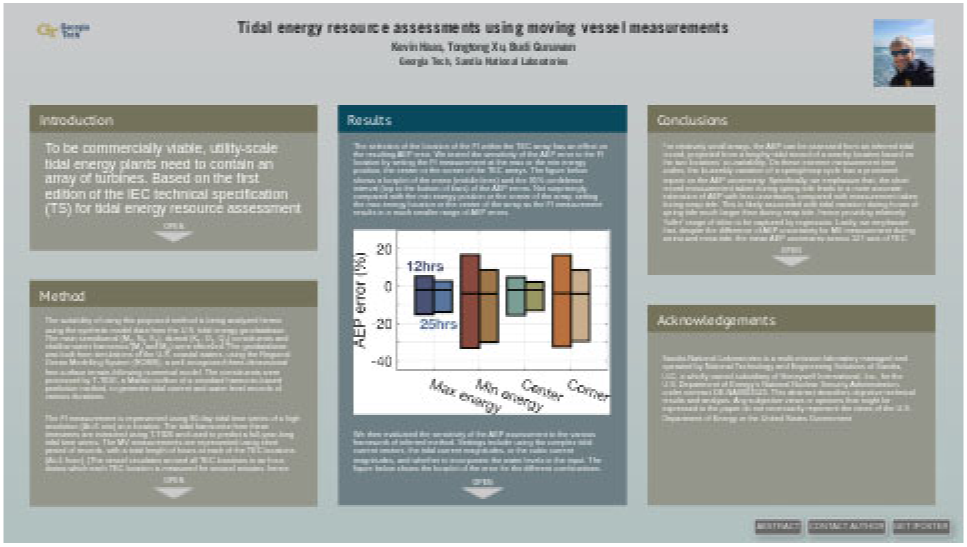
Tidal energy resource assessments using moving vessel measurements



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PRESENTED AT:

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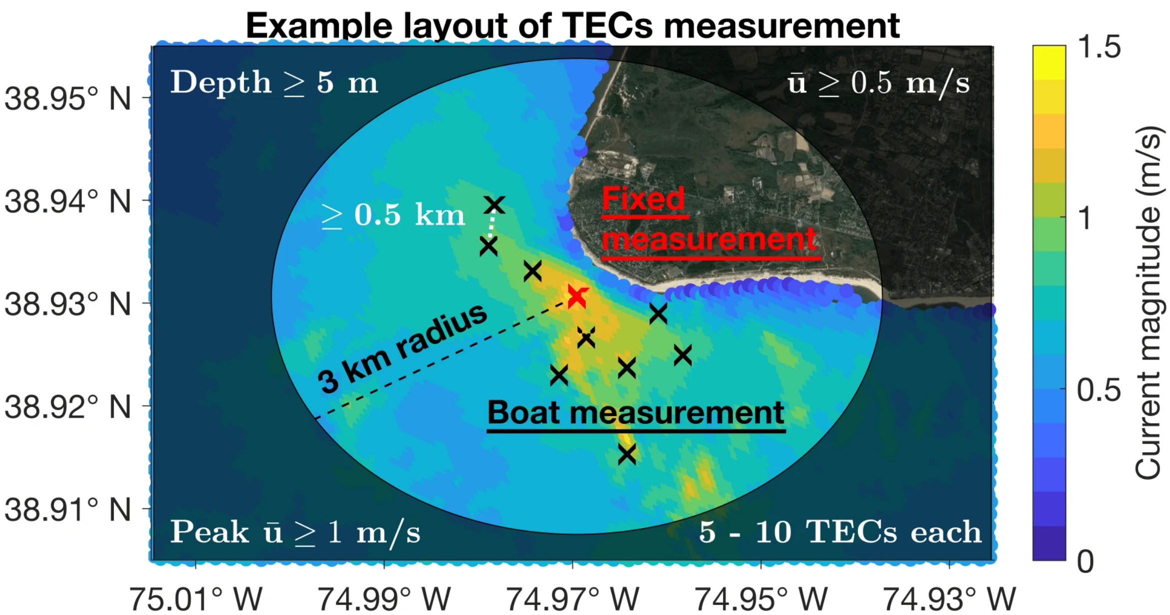
INTRODUCTION

To be commercially viable, utility-scale tidal energy plants need to contain an array of turbines. Based on the first edition of the IEC technical specification (TS) for tidal energy resource assessment and characterization, TS 62600-201, to be able to assess the annual energy production (AEP) of the array, a sufficiently long tidal current record at each tidal energy coverter (TEC) location is required. However, conducting long-term direct measurements at each individual TEC location using current profilers can be cost prohibitive, especially if a large number of TECs is proposed for the site. As a means to reduce measurement cost, a new approach is under consideration to provide estimates of the probability distribution at additional TEC locations, coupling one or more fixed instrument (FI) current profiler measurements with mobile vessel (MV) current profiler measurements. It is much more affordable to deploy a long-term bottom-mounted instrument at one site and conduct short-record boat-based measurement for the others than deploying a long-term bottom-mounted instrument at each proposed TEC locations. We present the proposed guidelines for the method to determine the AEP for a TEC array using this new approach.

The figure below shows an example layout of the a TEC array.

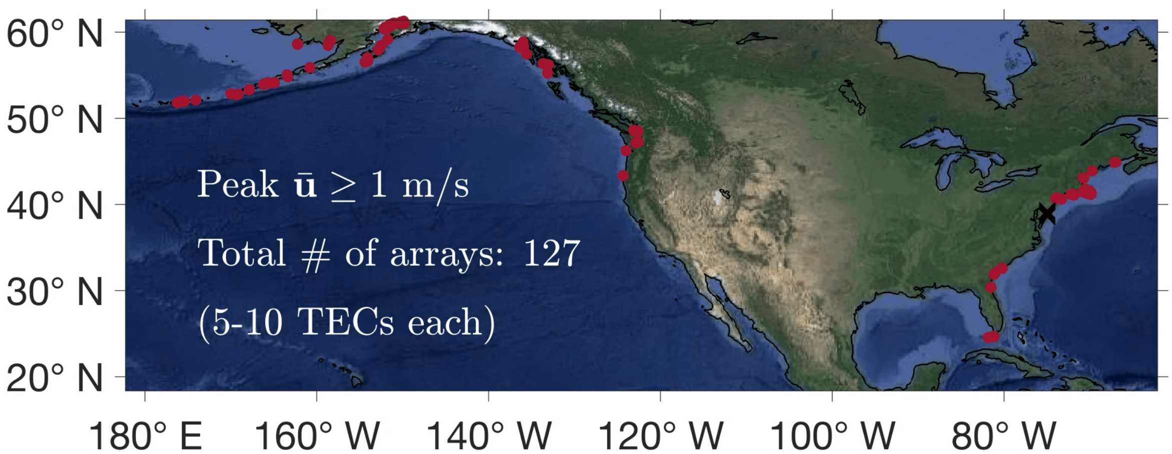


METHOD

The suitability of using this proposed method is being analyzed herein using the synthetic model data from the U.S. tidal energy geodatabase. The main semidiurnal (M_2, N_2, S_2), diurnal (K_1, O_1, Q_1) constituents and shallow water harmonics (M_4 and M_6) were retrieved. The geodatabase was built from simulations of the U.S. coastal waters, using the Regional Ocean Modelling System (ROMS), a well-recognized three-dimensional free-surface terrain-following numerical model. The constituents were processed by T-TIDE, a Matlab toolbox of a standard harmonic-based prediction method, to generate tidal current and water level records of various durations.

The FI measurement is represented using 90-day tidal time series of a high resolution (Δt=6 min) at a location. The tidal harmonics from these timeseries are extracted using T-TIDE and used to predict a full-year-long tidal time series. The MV measurements are represented using short period of records, with a total length of hours at each of the TEC locations (Δt=1 hour). [The vessel circulates around all TEC locations in an hour, during which each TEC location is measured for several minutes, hence the approximately 1-hour resolution at each TEC.] A full-year-long tidal current record at each TEC location is inferred from the FI measurement, through a least-square regression method.

For a robust assessment of the uncertainty behind the regression-based array AEP, we defined 127 tidal energy sites shown below (each site consists of an array of TECs).

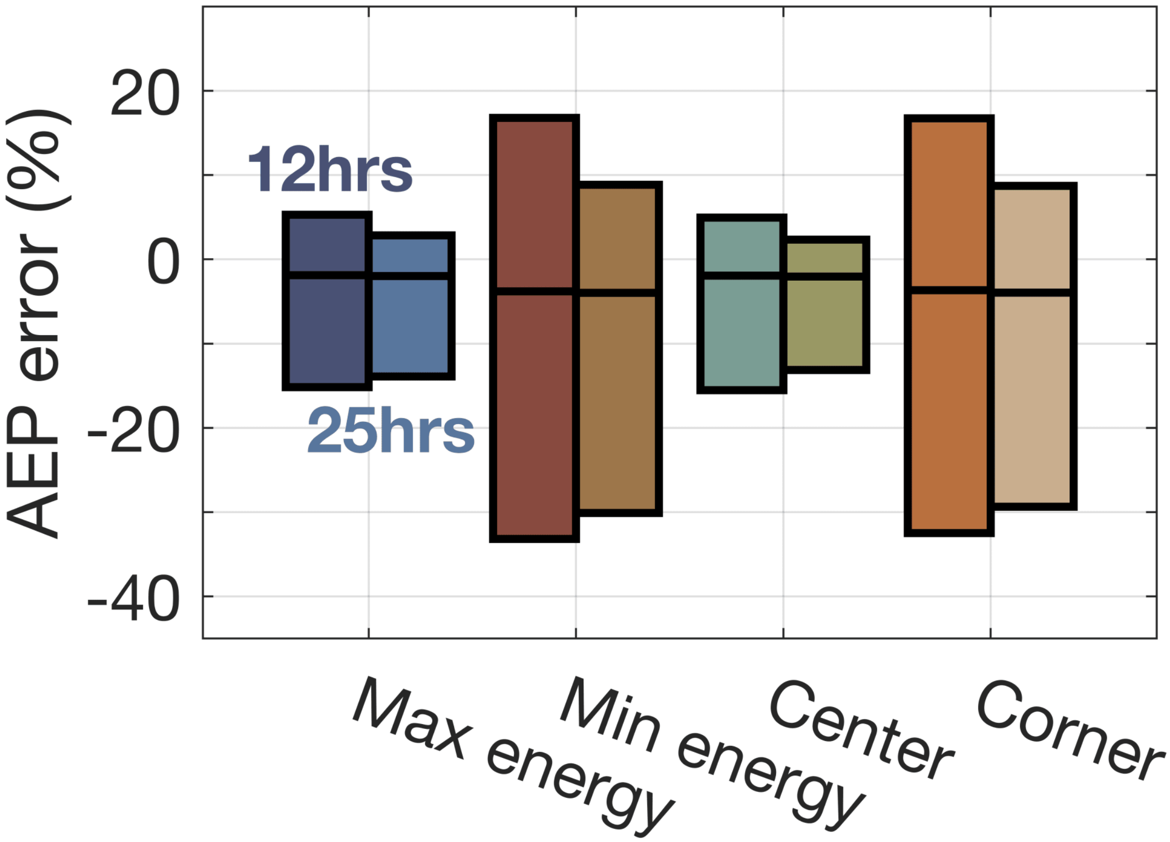


At each site, one TEC location is selected as the FI location. The rest of the sites are the MV measurement locations, at each of which we randomly sampled 500 timestamps out of the 2012 records. The tidal current records that start from these sampled timestamps were then extracted at a one-hour sampling rate. Record durations vary from 12 to 240 hours.

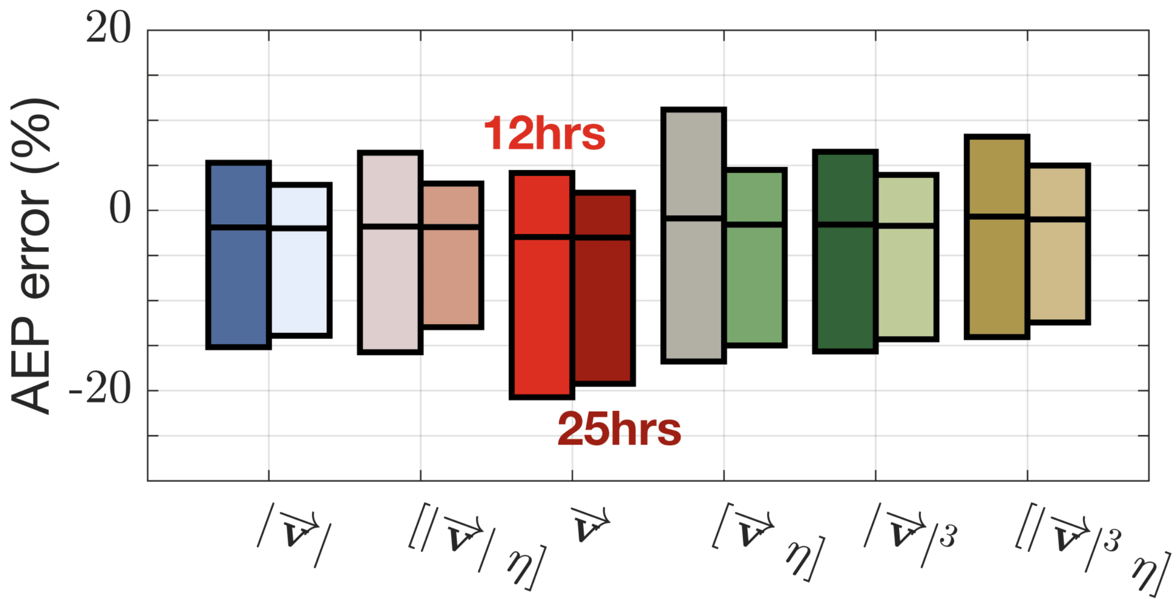
The AEP error is computed by comparing the array AEP calculated with this method to the to the array AEP computed using 1 year time series at every TEC location.

RESULTS

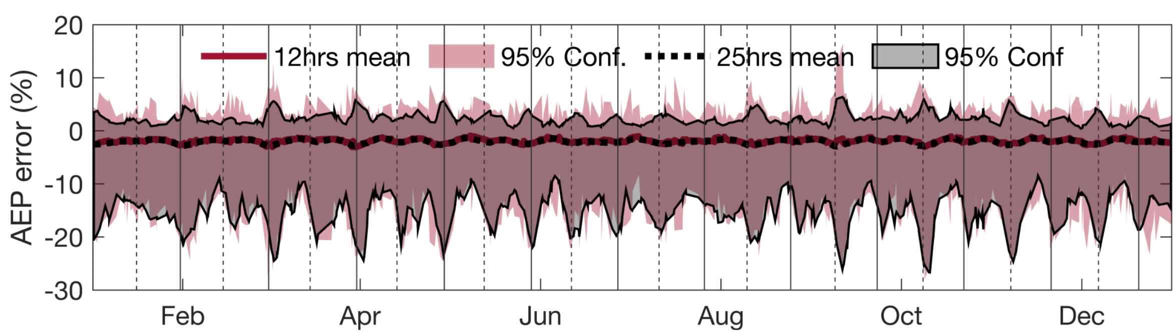
The selection of the location of the FI within the TEC array has an effect on the resulting AEP error. We tested the sensitivity of the AEP error to the FI location by setting the FI measurement at the max or the min energy position, the center or the corner of the TEC arrays. The figure below shows a boxplot of the mean (middle lines) and the 95% confidence interval (top to the bottom of bars) of the AEP errors. Not surprisingly, compared with the min energy position or the corner of the array, setting the max energy location or the center of the array as the FI measurement results in a much smaller range of AEP errors.



We then evaluated the sensitivity of the AEP assessment to the various framework of inferred method. Settings include using the complex tidal current vectors, the tidal current magnitudes, or the cubic current magnitudes, and whether to incorporate the water levels in the input. The figure below shows the boxplot of the error for the different combinations. Among these settings, building the regression solely based on the tidal current magnitude time series (first two bars of the figure below), one of the simplest frameworks, might be a robust option.

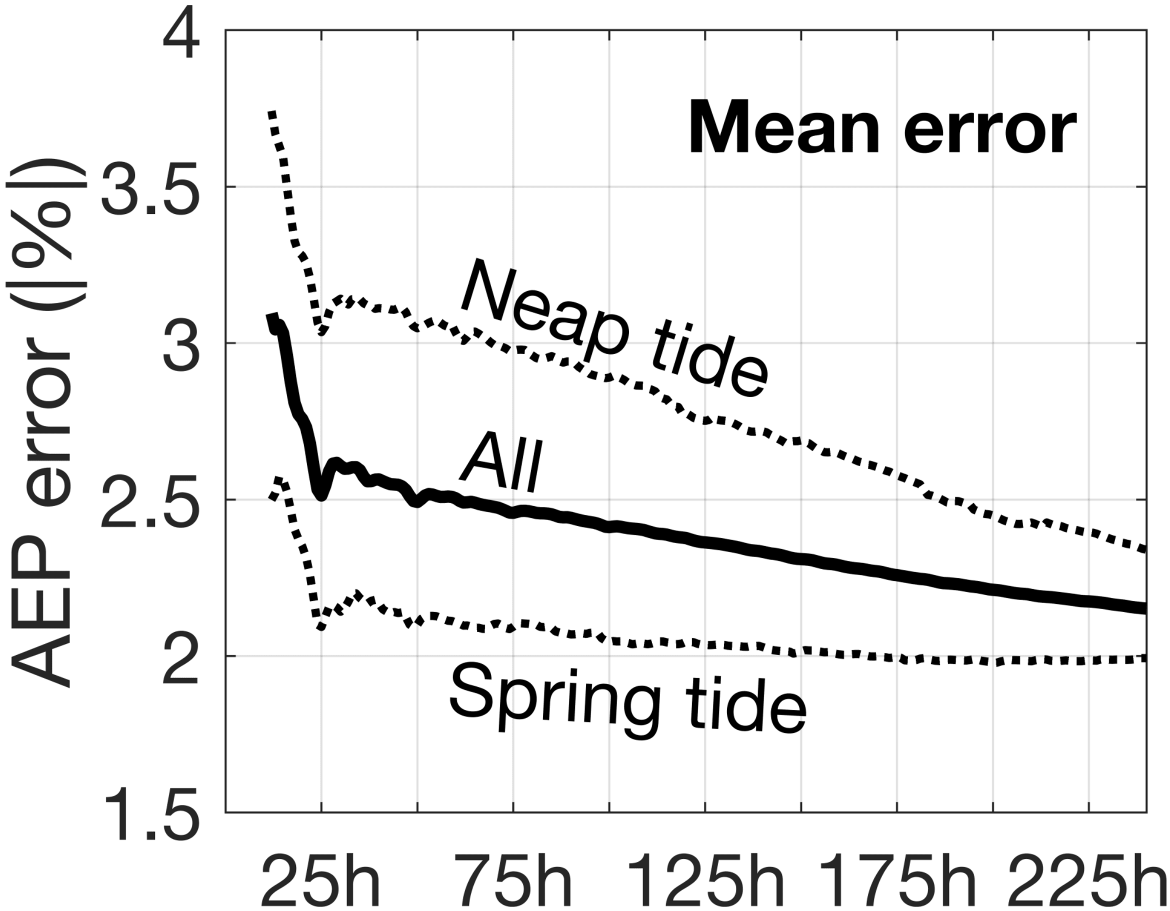


The variation of the AEP uncertainties based on the measurement period for 12 or 25 hour MV measurements are shown below. The results show a relatively steady mean error of -3%, suggesting that the strategy of combining a FI and a MV measurement is a viable option while also suggesting to some degree the underprediction of the available AEPs when applying our inferred framework.



More interestingly, the temporal variation of the AEP errors shows a clear fluctuation with respect to spring/neap cycle. Specifically, the AEP errors reach to local extremes, when the MV measures neap tides (vertical gray lines). In contrast, the range of AEP errors is the smallest when measuring spring tides (in between gray lines).

To rigorously quantify how the AEP errors vary as the MV measures spring vs. neap tide, we analyze AEP uncertainty derived from various MV measurement durations, ranging from 12 to 240 hours (solid line below). Results are further classified into AEP errors measured during spring vs. neap tides (dashed lines). For MV measurement during spring tide, the mean error is ~2.5% which is relatively steady and does not significantly change with increasing measurement duration. For MV measurement during neap tide, the mean error gradually decreases from 3.8% to 2.3% and the extreme error decreases from 13.8% to 9%, as the durations increase from 12 to 240 hours. Overall, these results support that the AEP errors are largely associated with the spring/neap cycles.


Mean error
AEP error (|%|)
4
3.5
3
2.5
2
1.5
Neap tide
All
Spring tide
25h
75h
125h
175h
225h

CONCLUSIONS

For relatively small arrays, the AEP can be assessed from an inferred tidal record, projected from a lengthy tidal record of a nearby location based on the two locations' co-variability. On these extreme measurement time scales, the bi-weekly variation of a spring/neap cycle has a prominent impact on the AEP uncertainty. Specifically, we emphasize that, the short record measurement taken during spring tide leads to a more accurate estimation of AEP with less uncertainty, compared with measurement taken during neap tide. This is likely associated with tidal variation during hours of spring tide much larger than during neap tide, hence providing relatively "fuller" range of tides to be captured by regression. Lastly, we emphasize that, despite the difference of AEP uncertainty for MV measurement during spring and neap tide, the mean AEP uncertainty across 127 sets of TEC arrays is only 3%, hence the robustness of the inferred method.

ACKNOWLEDGEMENTS

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